CLAY MINERAL DISTRIBUTIONS WITHIN LAKE ERIE'S WESTERN BASIN

By

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ABSTRACT

Sediment samples taken from the Detroit, Maumee, Portage, and Sandusky Rivers were analyzed for their clay mineral contents by a procedure that may be called semi-quantitative in its nature. This data was then compared with similar data from sediment samples taken within the Western Basin of Lake Erie, in order to establish a general sediment distribution pattern based on traceable clay mineral assemblages of the fluvial sediments.

The clay minerals were identified and semi-quantitatively analyzed by comparing characteristic basal peak areas read from x-ray diffractogram patterns The data show that there is a definate uniformity in clay mineral percentages of both the sediments being transported by the rivers emptying into the Western Basin of Lake Erie and the surficial basin sediments.

Because of this uniformity, mineralogical distinctions based solely on clay mineral assemblages cannot be made; in addition, no general conclusions be drawn as to overall distribution patterns of fluvially transported sediments within the waters of the Western Basin of Lake Erie.

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INTRODUCTION

The various fine-grained sediments (specifically the clay minerals) derived from any one source area reflect, either directly or through chemical alteration, the parent material found in that particular area. The object of this study was to determine if a mineralogical distinction can be made between clay-sized material derived from the major drainages emptying into the Western Basin of Lake Erie. If the source areas are mineralogically distinguishable, then these characteristic clay mineral assemblages can be traced into the basin to determine sediment distribution patterns.

Once clay mineral assemblage dispersion patterns within the Western Basin are known, a general sediment distribution model can be constructed for that basin. Such a model can have important implications for the study of pollutant and material transfer patterns within the lake. In addition, information of this kind can aid geologists in interpreting various source areas (provenance) for the sediments in other recent, as well as ancient, lacustrine deposits.

A general distribution model based on the mineral assemblages of fluvial sediments has not previously been attempted in the Great Lakes region. Within this region, fairly uniform rock types and large quantities of glacial sediments tend to produce only subtle differences in fluvial sediment compositions. Therefore, as a whole, the sediments from the various drainages were expected to be very similar in mineral composition. Within certain size fractions, however, it was hoped that differences in mineral assemblages from each drainage would be distinct enough to be traceable into the basin.

Lake Erie Background

Lake Erie, the second smallest of the five Great Lakes, borders the midwestern United States and the southwestern portion of Ontario. Its long axis, trending approximately N-NE, is about 50 miles long. Lake Erie is the shallowest of the Great Lakes, having a maximum depth of 210 feet (Wall, 1968). Physiographically, the Lake can be divided into three distinct basins. The Eastern Basin, being the deepest of the three, is bounded on its western margin by a bottom topographic high which trends approximately S 30 E. West of this high, the bottom gently slopes downward onto the broad, flat Central Basin. The western end of this relatively shallow central basin is marked by a series of islands and shoal areas which separate it from the shallow Western Basin (Wall, 1968). Figure 1 (below) shows Lake Erie and the approximate boundaries of her three basins.

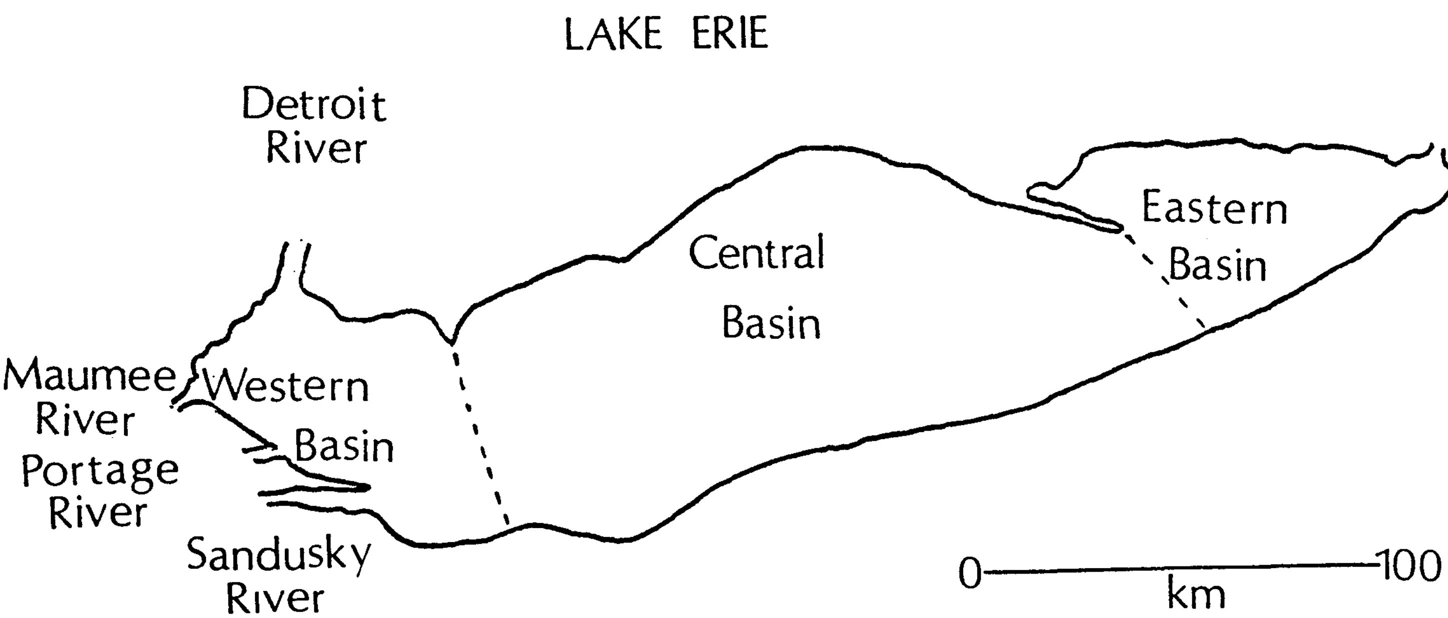

Figure 1. Lake Erie basin bounderies and locations of major river mouths.

Water circulation patterns within the lake are largely the result of discharge from the Detroit and, to a lesser extent, the Maumee Rivers. Currents tend to flow from the main water sources in the Western Basin of the lake to the single drainage (the Niagera River) in the Eastern Basin. Prevailing wind directions also play an important role in current directions; however, wind influences tend to affect only the uppermost water layers (Simons, 1976). Figure 2 (below) shows depth averaged current velocities in the lake during the period from July 16 through August 16, 1970.

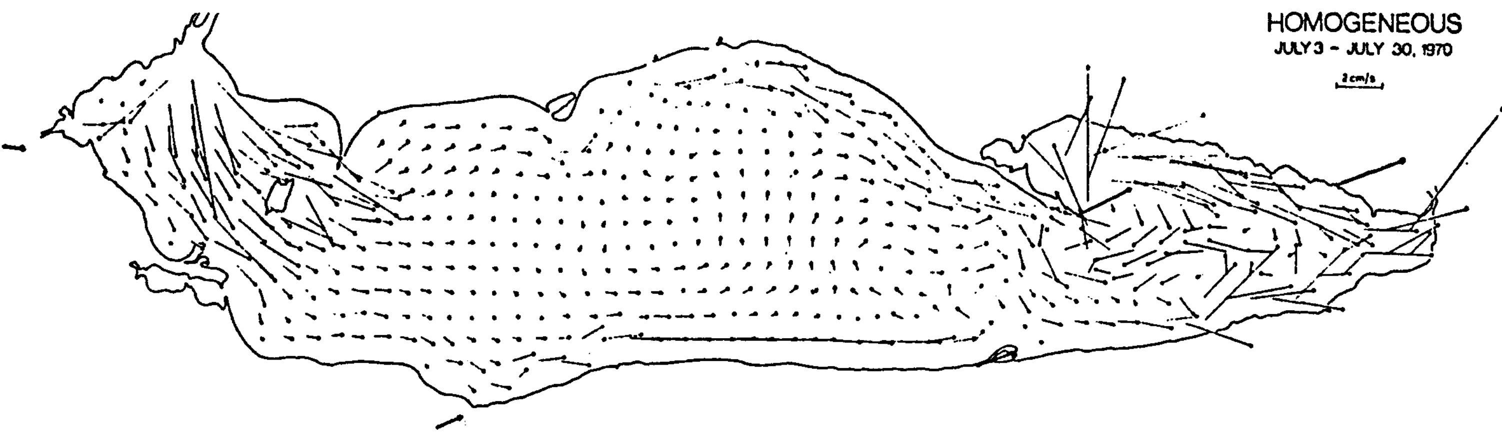

Figure 2. Computed Lake Erie water circulation for indicated period. Taken from Continuous Dynamic Computation of Water Transports in Lake Erie for 1970, J. of Fish., Res. Board Can., Vol 33, Simons, 1976.

Sediment Sources

A total of of 14.3 million metric tons of fine-grained sediment is being carried into the lake annually. The major contributor of the sediment load comes from erosion of shoreline bluffs, which accounts for over 40% of the total. Rivers, carrying the fluvial sediments being studied in this project, are the second largest source of fine-grained sediments to the lake basins. Rivers alone account for 4.1 million metric tons of sediment input annually (Kemp, MacInnis & Harper, 1977). Figure 3 (below) shows the different sources of fine-grained sediments and amount contributed by each annually (in millions of metric tons).

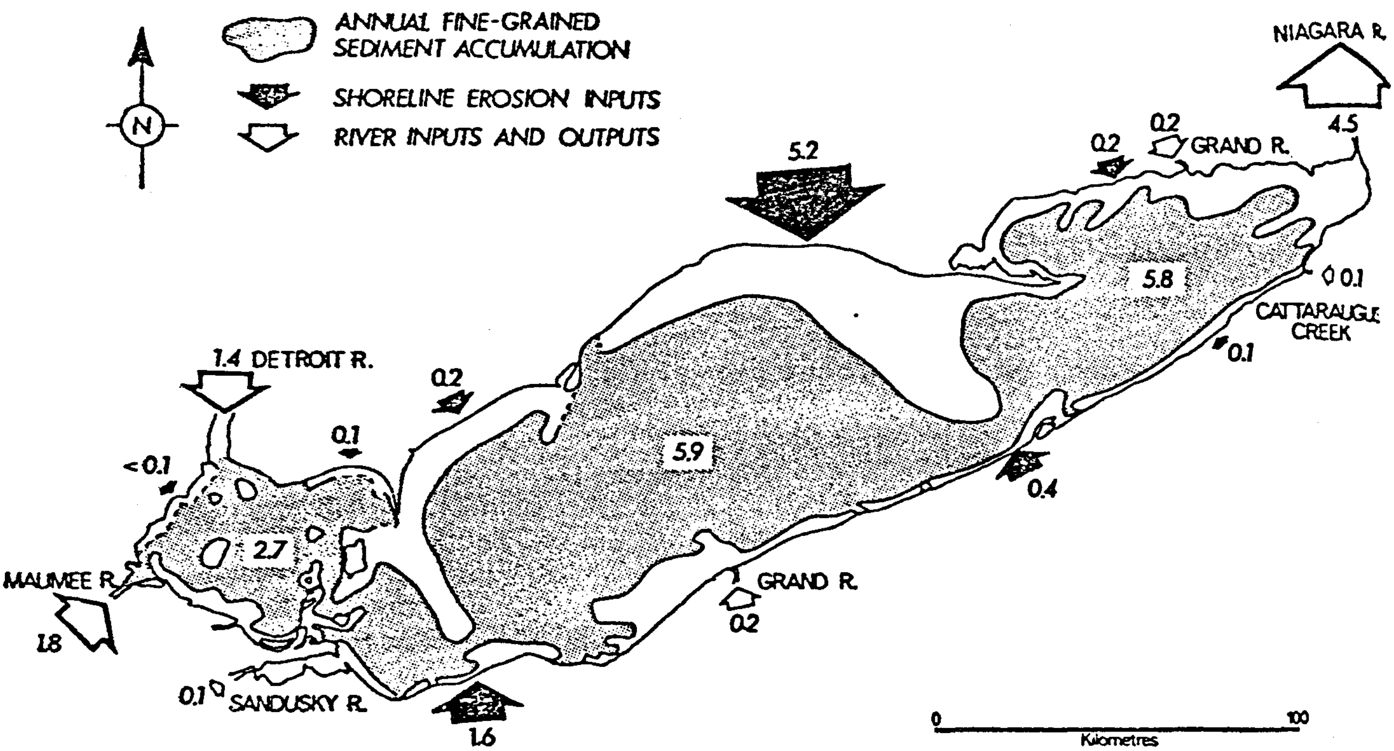

Figure 3. Major sources and sinks of fine grained sediment material in the Lake Erie drainage basin (millions of metric tons). Taken from Sediment Rates and Revised Sediment Budget for Lake Erie, J. Great Lakes Res., Kemp, MacInnis & Harper, Dec. 1977.

Shoreline erosion is concentrated along the North and South shores of the Lake (see figure 3) and primarily contributes sediments to the Central and Eastern Basins. Fluvially transported materials make up the bulk of the Western Basin's sediments, since this is the closest of the three basins to the major river mouths. Specific sediment distribution patterns within the Lake have not as yet been fully established.

Literature Review

Studies of sediment distribution patterns involving clay minerals have been performed in the past in the deep sea, as well as in lake basins. Pierre Biscaye (1965) was one of the first to conduct such a study. Biscaye analyzed over 500 Atlantic Ocean deep sea cores for the their clay mineral assemblages and compared these data to compositions of the sediment carried into the Atlantic by the major river systems. Biscaye concluded that generalized distribution patterns of the clays were present within the basin; as a result, he was able to determine the source area (provenance) for the sediments found in specific regions of the Atlantic (Biscaye, 1965). Other published studies of clay mineral distributions include Duncan, Kulm and Griggs' research on late Pleistocene and Holocene sediments of the Cascadia Basin in the northeastern Pacific (Duncan, Kulm and Griggs, 1970) and Pinet and Morgan's clay provenance studies in Georgian estuaries (Pinet and Morgan, 1979). Countless other clay mineral distribution studies are available in the literature.

Another pertinent study was conducted by Krissek and Scheidegger (1981). In this work, it was shown that mineralogical distinctions could be made on clay size fractions of sediments derived from various continental source areas. These assemblages were then traced offshore for a relatively long distance, and were used to model sediment distribution patterns from source area to marine sediments (Krissek and Scheidegger, 1981). According to Dr. Krissek, now from the Ohio State University, no such study has previously been attempted in an area such as the Great Lakes, where the various fluvial source areas are fairly uniform in lithology.

Recent studies of heavy metal distributions within the Western basin of Lake Erie (Walters, Kovacik and Herdendorf, 1974; Thomas and Jaquet, 1976) have shown that the major source of mercury contamination in the Western Basin is coming in through the Detroit River. This mercury is subsequently being distributed throughout the lake (see figure 4). Consequently, studies of this kind have, in effect, indirectly identified a distribution pattern for the sediments entering the Western Basin from the Detroit River. This study is only one-dimensional, however, in that it ignores the distribution patterns of the sediments brought into the Western Basin by other rivers, especially the Maumee, the Sandusky and the Portage. It is for this reason that a more complete study, modeled after Biscaye's monumental work, was conducted here.

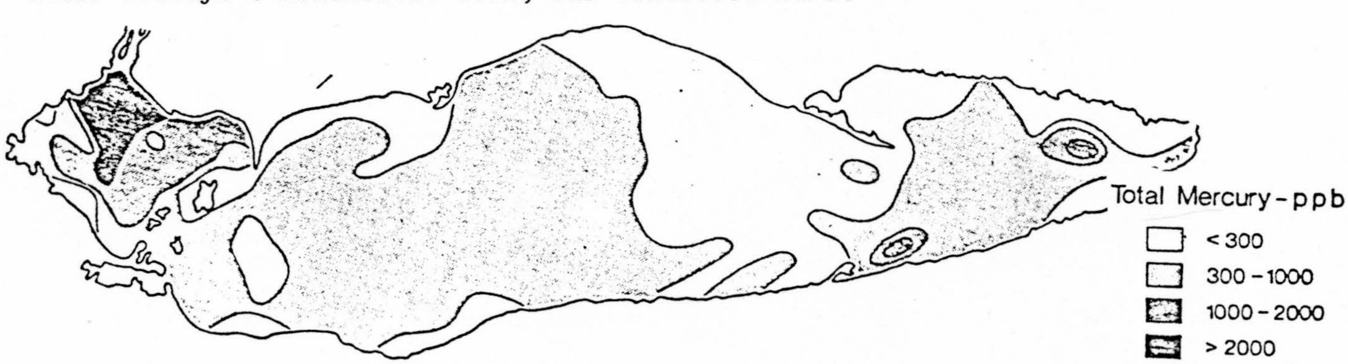

Figure 4. Distribution of total mercury in the surficial 3 cm of sediment in Lake Erie. Taken from Mercury in The Surficial Sediments of Lake Erie, J. Fish. Res. Board Can., Vol 33, Thomas & JaQuet, 1976.

FACTUAL SUMMARY

The study area is located in the Western Basin of Lake Erie, not far from the mouth of the Maumee River. Eleven samples, taken from the top 3-5 cm of lake bottom sediment, were obtained from the University of Toledo's Subsurface Data Center in Toledo, Ohio. Figure 5 (below) shows the area of study in relation to the lake as well as the locations where samples were taken.

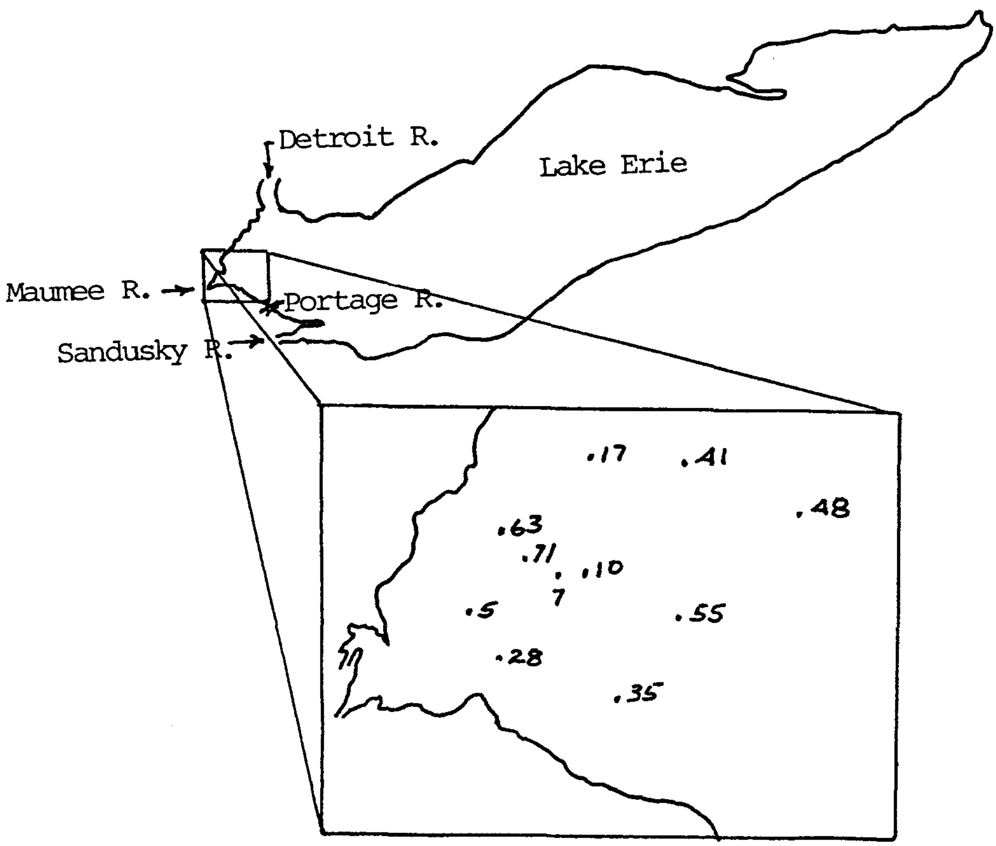

Figure 5. Sample cites within the Western Basin. Modified map of Original, Compliments of Division of Geological Survey, Lake Erie Section

Preparation of Sample

Sample preparation basically involved disaggregating and separating the clay size (less than 2μm) fraction from the sediment samples and preparing a glycolated, oriented mount of each sample. The samples varied in particle grain diameter within a range of fine sand to clay sizes. The sediment also contained small amounts of organic matter. The samples were treated with a hydrogen peroxide solution to dissolve the organic matter and were then size fractionated in settling jars to obtain the less than 2μm fraction. Magnesium chloride was added to the samples to ensure uniform cation saturation before mounting. The samples were then each mounted on standard glass slides. Finally, upon drying, the samples were glycolated for 24 hours at a temperature of 60° C. Glycolation was performed to expand the montmorillonite d-spacings from 15Å to 17Å, making the montmorillonite (001) diffraction peak more distinguishable from the 14A chlorite (001) peak.

Mineral Identification

The clay minerals observed in this study (kaolinite, chlorite, montmorillonite and illite) were identified by their characteristic basal x-ray diffraction maxima, here called peaks. The mounts were x-rayed using CuKα radiation at a scan rate of 1° 2θ per minute in the 3° 2θ - 20° 2θ range and at a scan rate of 1/2° 2θ per minute in the 23° 2θ - 27° 2θ

range. Table 1 is a list of the characteristic peaks used in this study to identify each mineral, the mineral diffraction plane which produced these peaks, the d-spacing (in angstroms) of these diffraction planes, and the 2θ value corresponding to each d-spacings.

TABLE 1

MINERAL	DIFFRACTION PLANE	D-SPACING	2θ VALUE
montmorillonite	(001)	17Å	2.6
illite	(001)	10Å	8.7
chlorite	(002)	7Å	12.4
kaolinite	(001)	7Å	12.4
chlorite	(004)	3.54Å	25.15
kaolonite	(002)	3.56Å	24.88

Figure 6a (page 10) shows the representative peaks for the illite (001) and kaolinite (001) plus chlorite (002) diffraction planes on a diffractogram pattern of sample #10 run from 3° - 20° 2θ. Figure 6b (page 10) shows the chlorite (004) and the kaolinite (002) diffraction peak run on the same sample within the range of $23^{\circ} - 27^{\circ}\ 2\theta$. Notice on figure 6a that there is no apparent peak at $2.6^{\circ}\ 2\theta$. This suggests that there is no montmorillonite present at the location that this sample was taken from. This lack of montmorillonite was consistently observed in all 11 of the samples collected; therefore, there seems to be no appreciable quantities of montmorillonite throughout the sample area of the Western Basin.

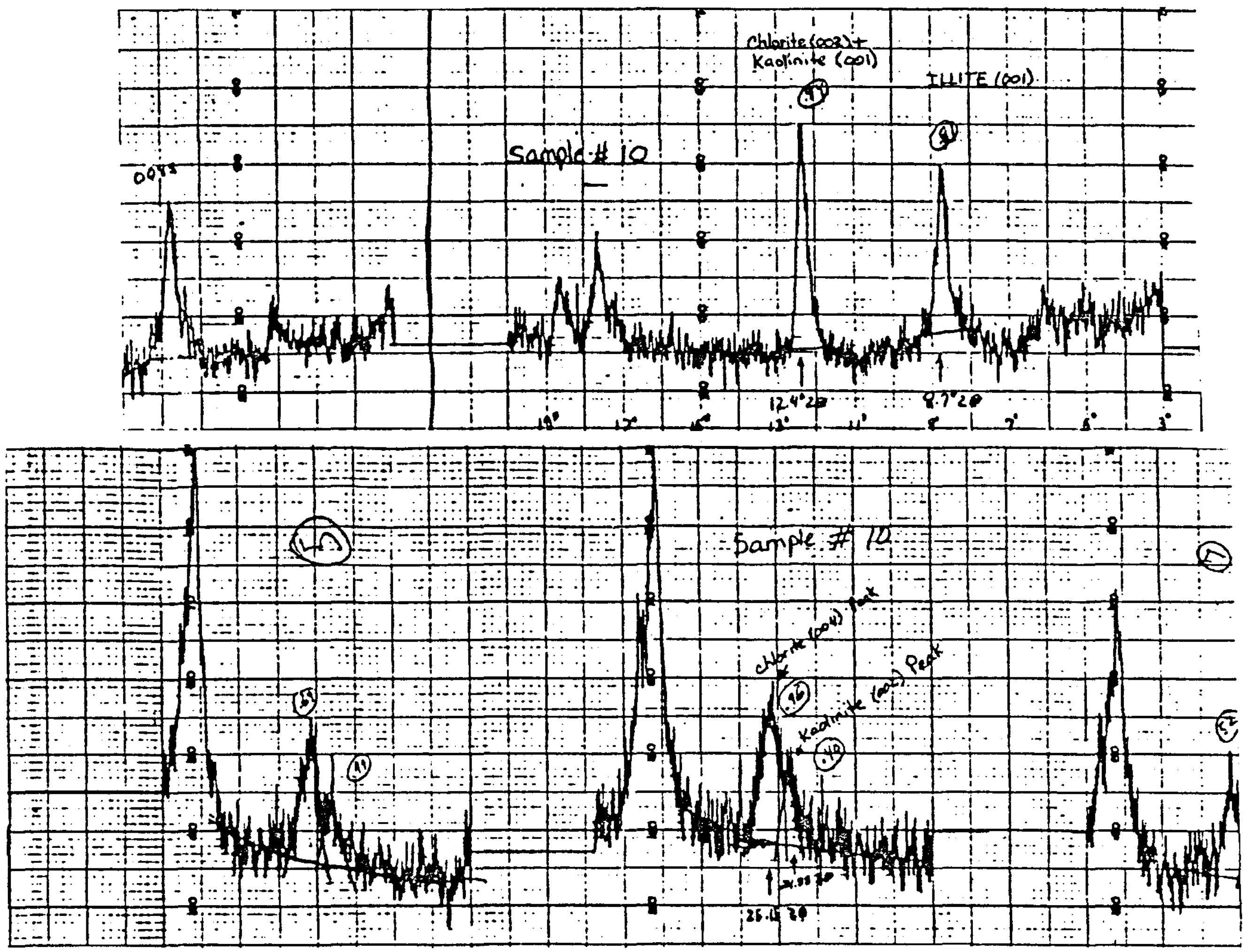

Figure 6. X-Ray diffractogram patterns showing (a) Illite (001) and Chlorite (002) plus Kaolinite (001) peaks, and (b) the Koalinite (002) and the Chlorite (004) peaks.

Sample Mineral Identification

After the clay minerals were identified, the next step was to determine the amount of each clay type present in each of the samples. Because truly quantitative evaluations of complex clay mineral assemblages are not easily performed, a measurement which may be called semi-quantitative in nature was made. Characteristic mineral peak intensities cannot be directly used as a measure of mineral abundances within samples. This is because fluctuations in diffractogram patterns often result from slight variations in x-ray machine conditions, preferred orientation of sample mounts, slide thicknesses, and degree of mineral crystallinity. Useful comparisons, however, can be made from sample to sample by using various ratios of peak areas measured for each diffractogram.

In this study, relative clay mineral abundances were calculated using a construct similar to that proposed by Biscaye (1965) for analysis of ocean sediments. Percentages of each of the clay mineral components have been calculated based upon the area of their characteristic basal diffraction peaks. The areas of these peaks were read directly from the diffractogram patterns with the use of a planimeter. The areas of the kaolinite (001) plus chlorite (002) and illite (001) peaks were weighted by integer values; the sum of the weighted peak areas was then set equal to 100% of the sample clay mineralogy according to the following formula (Biscaye, 1965):

((glycolated montmorillonite (001) peak area)) + 4((illite (001) peak area)) + 2((kaolinite (001) plus chlorite (002) peak areas)) = 100%

Note: Because no montmorillonite was found in any on the 11 samples,the montmorillonite peak area was set equal to zero in this equation.

The weighted peak areas were summed and set equal to 100% of the clay mineralogy of the sample. The weighted area of each mineral was then multiplied by 100 and divided by the sum of the weighted peak areas to give the percentage of the total clays contributed by each component. The result of the calculation was an estimate of the illite percentage and the combined percentage of chlorite and kaolinite in each sample.

Relative peak areas for the kaolinite (002) and the chlorite (004) peaks were then measured on the diffractogram patterns (figure 6b) in the same way as before, and used to determine the contributions to the chlorite (002) plus kaolinite (001) diffractogram peak area from chlorite and from kaolinite. This estimate was made by adding the peak areas of the chlorite (004) and kaolinite diffractions, and setting this sum equal to 100% of the kaolinite plus chlorite percentage calculated as described above. The peak areas of the kaolinite (002) and chlorite (004) diffractions were then each divided by their total area and multiplied by the previously determined chlorite plus kaolinite percentage to estimate the individual abundance of each mineral. The results of these calculations are listed in Table 2 and shown graphically in figure 7.

TABLE 2

Sample #	Illite %	Chlorite %	Kaolinite %
71	62.3	29.1	8.6
28	71.1	21.2	7.7
35	71.4	19.2	9.4
63	70.9	29.1	0.0
55	66.8	22.4	10.8
7	68.1	22.7	9.2
5	68.8	19.1	12.1
10	63.3	25.9	10.8
48	62.5	37.5	0.0
17	65.7	26.5	7.8
41	67.5	24.3	8.2

Fluvial Mineral Assemblages

In order to trace sediment distribution patterns, the clay mineral assemblages found within the sediments of the basin must be compared to the clay mineral assemblages found in the sediments carried into the basin by the major rivers. Kaolinite, montmorillonite, chlorite, and illite percentages of fluvial sediments from the Detroit, Maumee, Sandusky, and Portage Rivers were determined from samples taken during December of 1982 and April of 1983 by Dr. Krissek from the Ohio State University (unpublished data). Because his data show small percentages of montmorillonite, his mineral percentages have been recalculated for the purposes of this comparison in order to make the percentages of kaolinite, chlorite, and illite equal 100%. TABLE 3 (below) lists the recalculated percentages of these three clay minerals found in the sediment sampled from the Detroit, Maumee, Sandusky, and Portage Rivers on the two sample dates given.

TABLE 3

Rivers	Illite %	Chlorite %	Kaolinite %
Detroit			
12/82	59.3	40.7	0.0
4/83	59.4	40.6	0.0
Ave.	59.35	40.65	0.0
Maumee			
12/82	72.4	27.6	0.0
4/83	67.2	32.8	0.0
Ave.	69.8	30.2	0.0
Portage			
12/82	77.4	22.6	0.0
4/83	72.5	27.5	0.0
Ave.	74.95	25.05	0.0
Sandusky			
12/82	60.8	21.4	17.8
4/83	67.9	10.6	21.4
Ave.	64.35	16.0	19.6

Sample Comparison

Tables 2 and 3 were plotted on a triangle graph to show the variations in mineral compositions between the various basin sediments and the various fluvial sediments (figure 7). The graph shows that the clay mineral percentages of both the fluvial and basin sample sedimemts are extremely uniform.

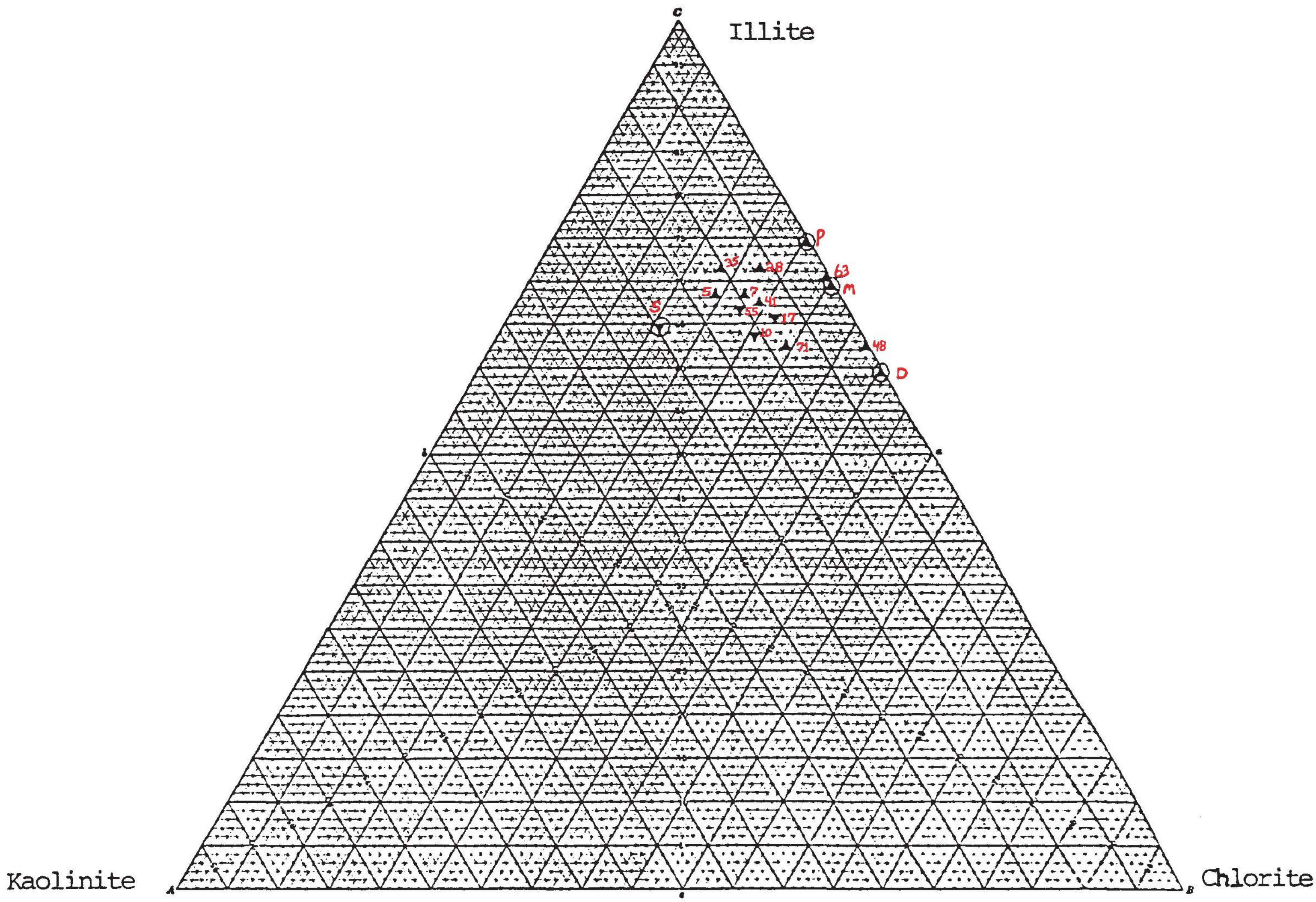

Figure 7. Graph showing mineral percentages of Kaolinite, Chlorite, and Illite for each sample. indicates fluvial samples and basin samples. D, M, P, S indicate Detroit, Maumee, Portage and Sandusky Rivers, respectively.

Figure 7 graph color enhanced with permission of advisor Lawrence Krissek 3-06-2015.

CONCLUSION

Because of the similarities in the clay mineral assemblages of the samples taken, mineralogical distinctions based on these assemblages cannot be made, nor can any general conclusions be drawn as to overall distribution patterns of fluvially transported sediments within the waters of the Western Basin of Lake Erie. Individual clay mineral distributions, however, are possible to trace throughout the sample area and can provide some useful information.

Figures 8, 9 and 10 are sediment clay mineral percentage contour maps for illite, chlorite and kaolinite within the sample area.
The average clay mineral percentage of sediments carried by each of the rivers are given for each of the four major rivers.

Illite

Illite percentage of sediments within the basin vary within a range of 74.95% down to 59.35%. The map in figure 8 shows an increase in an easterly direction of illite percentages in sediment samples.

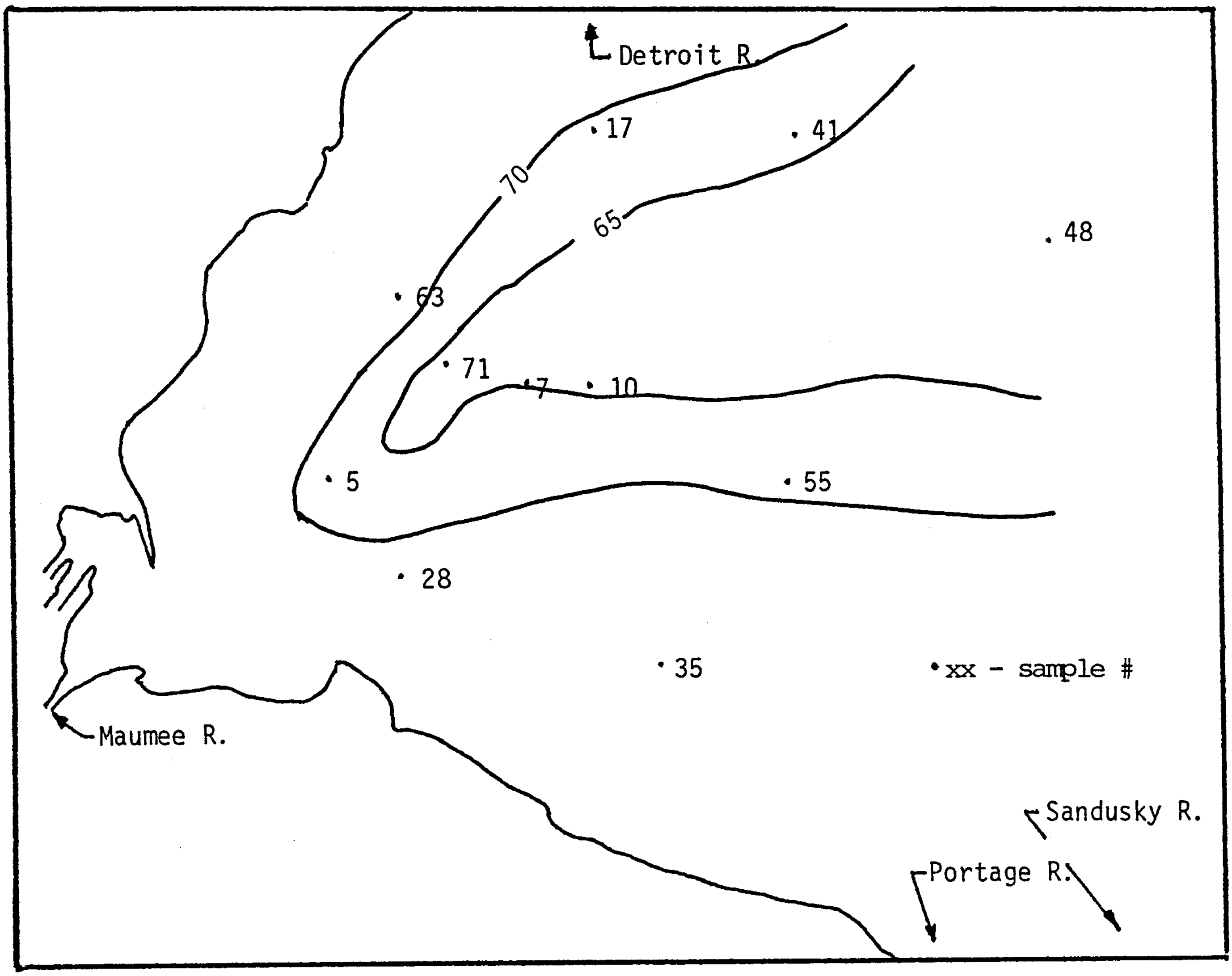

Figure 8. Illite percentages contour map based on 11 sediment samples taken within the basin. Also shown is the average percentage of Illite in the fluvial sediments carried by the Detroit, Maumee, Portage, and Sandusky Rivers.

Chlorite

Chlorite percentages of sediments within the basin vary within a range of 40.65% down to 16%. The map in figure 9 shows a decrease in chlorite percentages outside of a narrow band running south-easterly from the Detroit River.

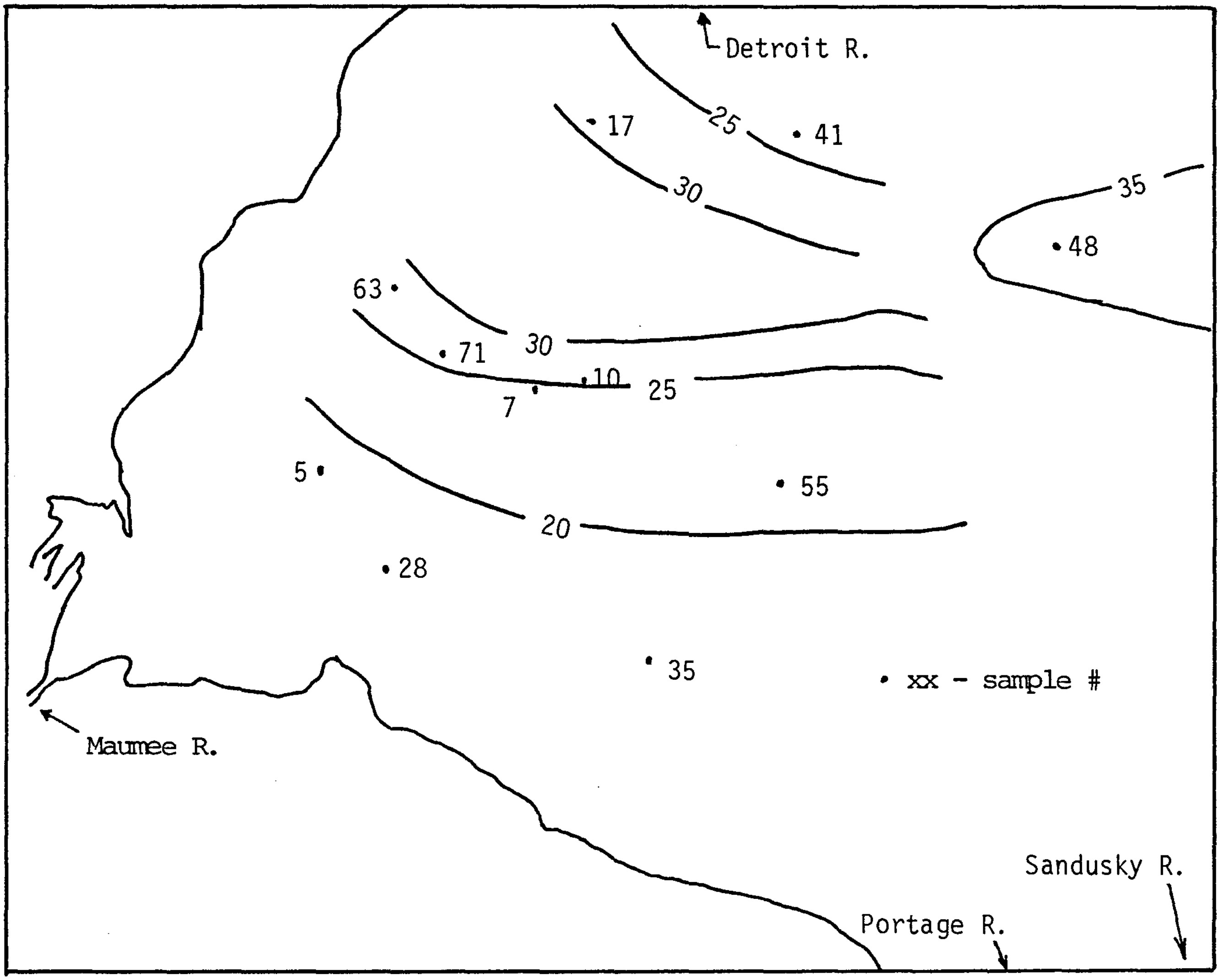

Figure 9. Chlorite percentages contour map based on 11 sediment samples taken within the basin. Also shown is the average percentage of Chlorite in the fluvial sediments carried by the Detroit, Maumee, Portage, and Sandusky Rivers.

kaolinite

Clay mineral kaolinite percentages within the basin (see Table 2) vary within a range from 12.1% down to 0%. The map in figure 10 was contoured to show locations of samples with clay mineral percentages over and under 10%. A trend indicated by the map is thet kaolinite percentages of the basin sediments tend to increase in samples taken closer to the Maumee River.

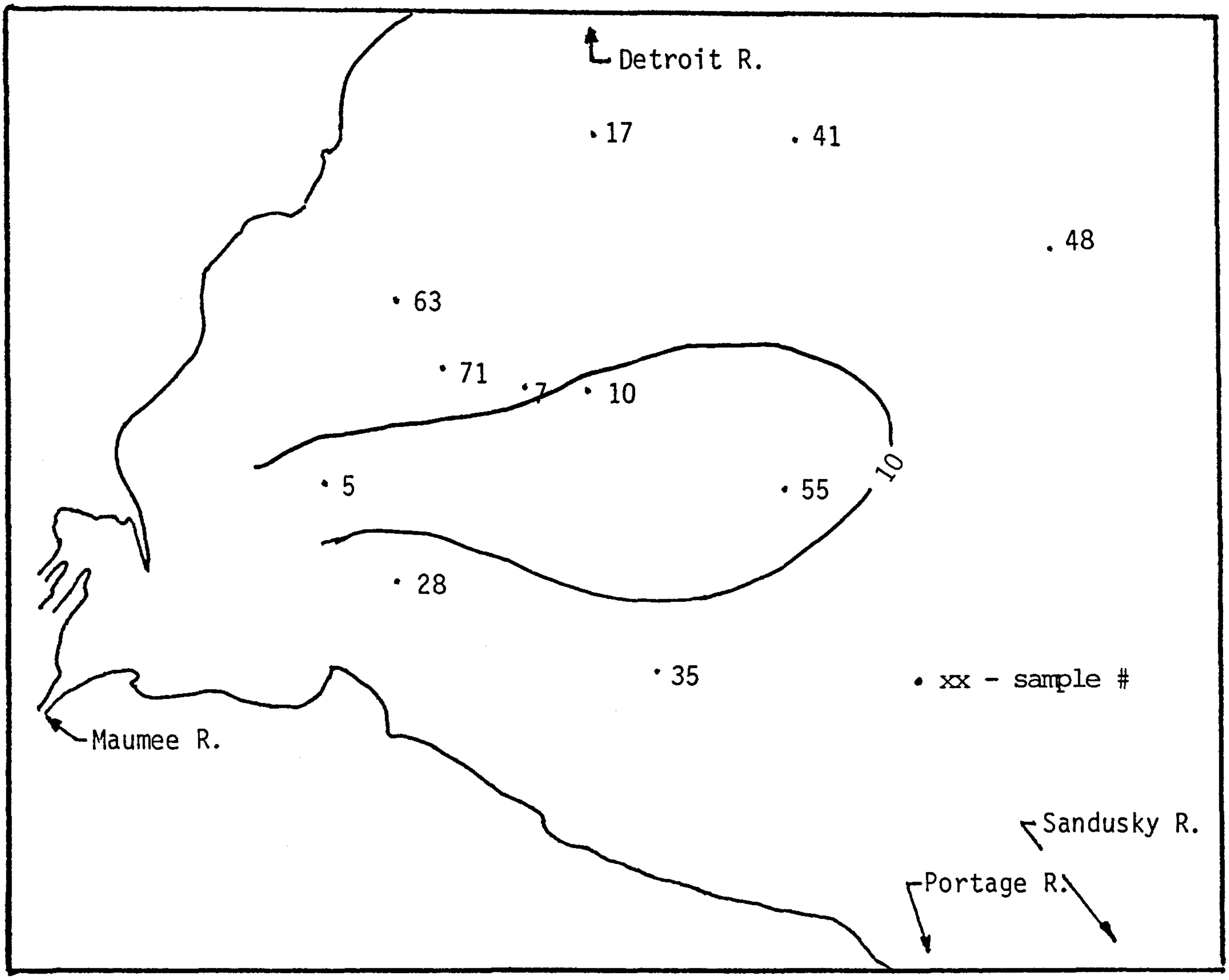

Figure 10. Kaolinite percentages contour map based on 11 sediment samples taken within the basin. Also shown is the average percentage of Kaolinite in the fluvial sediments carried by the Detroit, Maumee, Portage, and Sandusky Rivers.

RECOMMENDATIONS

This project dealt with only clay mineral assemblages of sediment samples in trying to construct a sediment distribution model for the basin. Because this study concluded that clay mineral assemblages alone do not provide useful sediment distinctions, a more complete study involving mineral assemblages of several combined size fractions be done. Such a study should include fractions of 2 - 4, 4 -10, 10 - 20, 20 - 40, and 40 - 62 μm.

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